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The rational exploitation of the Scottish-Norwegian stocks of spurdogs (*Squalus acanthias* L.)

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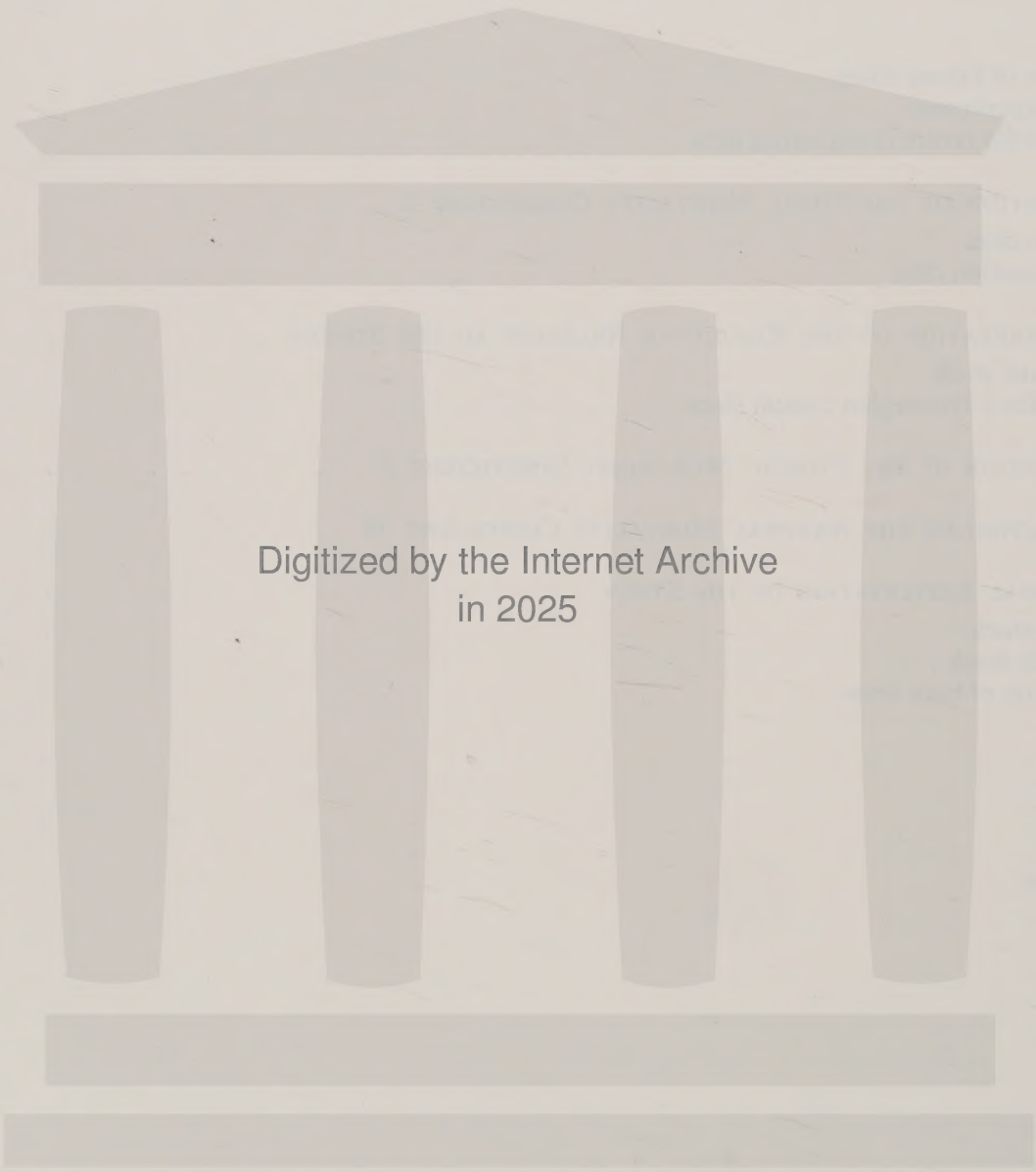

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The rational exploitation of the Scottish-Norwegian stock of spurdogs *(Squalus acanthias* L.)

INTRODUCTION

THE Scottish–Norwegian stock of spurdogs is that stock which inhabits the sea area from the Norwegian coast to west of the Shetland, Orkney and Hebridean islands. During the months April to October the major part of the stock is concentrated in the western half of this area; in November there is a movement of part of the stock to the Norwegian coast, followed by a return movement in March. These migrations have been described in detail by Holden (1965). Aasen (1964) considered that there was one stock of spurdogs that populated all the north-east Atlantic fishing grounds, and he called this the North-east Atlantic stock. Holden (1965) has shown that there are several stocks in the north-east Atlantic and that Aasen's results refer to what he terms the Scottish–Norwegian stock.

Using tag return data Aasen (1962) calculated that the total mortality coefficient Z for this stock was 0.287. From observations on the fecundity of the spurdog Holden and Meadows (1964) calculated that it was very improbable that this stock was replacing itself at this level of mortality and that a large decrease in its abundance must be expected. Later work by Aasen (1964) showed that the total mortality coefficient had increased to 0.72, a level at which the spurdog's low fecundity would make stock replacement impossible. However, Aasen, using Schaefer's method (Schaefer 1957), concluded that the annual catch at this rate of fishing was the maximum sustainable yield.

It was evident therefore that further analysis of the exploitation of this stock was necessary. Moreover, the Norwegian data take little account of the exploitation of the male stock. Returns from English tagging experiments show that the Norwegian fishery is most intense on female fish larger than 80 cm (that is, mainly mature fish), comparative returns being 9.9 per cent for females larger than 80 cm, 2.2 per cent for females smaller than 80 cm, and 2.6 per cent for all male fish. All lengths in this paper refer to total lengths. While it is important to protect the female fish to ensure the replacement of the stock, any conservation measures must also take into account the male fish. These attain a smaller maximum length than female fish (Holden and Meadows 1962) and therefore protection of the stock by the imposition of a minimum size limit, irrespective of sex, sufficient to protect the female stock could result in the male stock being under-exploited.

In this paper, therefore, in order to present a detailed picture of the exploitation of this stock the two sexes have been treated separately as far as is possible.

Table 1 Comparison of catch of spurdogs (as tons per 100 hours fishing) by Grimsby steam and motor trawlers, 1955 to 1959

Year	Steam	Motor	Steam/Motor
1955	14.6	13.4	1.09
1956	13.4	15.9	0.84
1957	12.8	11.5	1.11
1958	11.9	10.1	1.18
1959	13.6	13.9	0.98
Mean	*13.3*	*13.0*	*1.02*

Table 2 English spurdog-tagging experiments

Year	Month	Vessel	Cruise	Number of fish tagged	Area
1960	June–July	R.V. SIR LANCELOT	IX and X	1 442	North of Scotland
1961	June	R.V. CLIONE	X	3 042	North of Scotland
1961	July	R.V. CLIONE	XII	497	North of Scotland
1962	February	R.V. ERNEST HOLT	II	812	Norwegian Coast
1962	December	M.V. OCEAN STAR	—	2 008	North of Scotland

METHODS

ESTIMATION OF FISHING EFFORT

THE main English fishery on this stock is carried on by Grimsby trawlers. It is a complex fishery in that there is a limited demand for spurdogs on Grimsby market, with the result that the skippers of those trawlers which specialize in catching spurdogs usually plan their trips so as to catch the spurdogs they require near the end of the voyage. This is important because the fish are landed ungutted and if caught too early in the trip they are in very poor condition when landed. It is also common for boats fishing around Iceland and Faroe to spend a short time on the homeward voyage fishing on the north of Scotland grounds mainly for spurdogs. These trips are known as *split-trips* and it is usually impossible to ascertain, from the mates of these vessels when they land, the amount of time which has been spent fishing for spurdogs. Because it is unusual to catch any large quantity of spurdogs at either Iceland or Faroe, it has been assumed that all spurdogs landed from a *split-trip* were caught on the north of Scotland grounds, unless there was evidence to the contrary.

To obtain an index of fishing effort the catch per 100 hours fishing by all trawlers fishing either or both of statistical regions IVA and VIA, but no other regions, in a single trip and landing spurdogs was calculated monthly. The total monthly landings of spurdogs by all trawlers from these two regions was then divided by this index to give total effort. No distinction was made between steam and motor trawlers, because comparison of the catch per 100 hours fishing showed no difference in efficiency between the two types of vessel (Table 1). The data in this table refer only to those years in which sufficient numbers of both types of vessel were fishing to enable a valid comparison to be made.

TAGGING EXPERIMENTS

Tagging experiments were undertaken to obtain information about migration and mortality rates. Tagged fish were first released in this stock from English research vessels in 1960, and in that year's work four types of tags were used: Petersen discs, polythene flags on nylon bridles, polythene flags on wire bridles, and internal tags. The highest return rate was obtained from fish tagged with Petersen discs, and in subsequent tagging experiments, details of which are given in Table 2, only these were used. The 1960 experiment has been omitted from subsequent calculations, because there were too few returns to permit accurate estimates of the mortality rates to be made. During Cruise X/1961 of R.V. CLIONE and Cruise II/1962 of R.V. ERNEST HOLT the fish were classified as to condition. On the former cruise three categories of condition related to the degree of damage were used, as follows:

Good: fish unmarked;

Scratched: some scales dislodged; scratches present but skin not cut;

Lacerated: sub-cutaneous flesh showing through wounds.

On the latter cruise three categories (*good, moderate and poor*) were used as a general description of the condition and liveliness of the fish. The spurdogs tagged from the M.V. OCEAN STAR, a commercial seiner, all appeared to be in good condition; those released during Cruise XII/1962 of the R.V. CLIONE were not classified as to condition.

CORRECTION FOR ERRORS IN TAG RETURN DATA

Estimates of mortality rates derived from tag returns are subject to several sources of errors. These errors and their possible effects on the results described are:

1 *Death of fish immediately after tagging* From Cruise X/1961 of R.V. CLIONE the rates of recapture of fish in the two categories *scratched* and *lacerated* were lower than from the category *good*, but there was no consistent difference between the rates of return from the two former categories when analysed by sex and length. They were therefore grouped as *scratched plus lacerated.* From Cruise II/1962 of R.V. ERNEST HOLT there were consistent differences between the three categories *good*, *moderate* and *poor*. The returns for each category from both of these cruises are shown in Table 3, together with the estimated tagging mortalities. It has been assumed that there were no deaths, due to tagging, of fish in the category *good*; this is not necessarily correct, and the estimated number of survivals is therefore a maximum. For Cruise XII/1961 of R.V. CLIONE the survival ratio used, that is the estimated number of survivors divided by the number of fish tagged, was that for male fish released during Cruise X/1961 of R.V. CLIONE. The fish released from the M.V. OCEAN STAR were seine-caught and in very good condition compared with the trawl-caught fish released from the research vessels, and tagging mortality has been considered to be negligible.

2 *Incomplete reporting of tags* It was shown by Margetts (1963), for cod, haddock and plaice, that the rate of return of tags planted on the market may be very low, and a repetition of his work with spurdogs confirmed his findings. Of four fish tagged with Petersen discs and planted on Grimsby market after sales only one was returned. Although the number was small the results are very similar to those obtained by Margetts and can therefore be considered to give a reasonable estimate of the non-return rate. To eliminate this error the tag returns were split into two categories, before-sales returns (from crew and *lumpers*, the latter being the men who unload the fish) and after-sales returns (from buyers and skinners). The post-sales returns were raised by a factor of four and added to the before-sales returns to give the estimated number of tagged fish caught. This gave a raising factor of 1.97 for Grimsby landings (Table 4). The number of fish landed was known from market sampling, and the corrected return rate per million fish landed was calculated. The number of spurdogs landed at Fleetwood was also known from market sampling, and a raising factor of 1.18 for tag losses was calculated on the assumption that the return rate should be the same as at Grimsby; for Scottish landings it was assumed (in the absence of market measurements) that the size composition of the catches was similar to that of the Grimsby catches, and that it was possible to compare the returns on a weight basis. This gave a raising factor of 2.12 (Table 4).

Measurements of the Norwegian landings were also not available. To obtain an estimate of the number of fish in these catches the number of tag returns in each 10 cm length group was related to the number of fish tagged. The ratio of tags returned to tagged fish liberated was applied to the Grimsby landings, which were assumed to be a true sample of the population, to give an estimate of the size distribution of the Norwegian landings. The mean weight of the fish in the catch, estimated by this method, was 2.3 kg, and the total number of fish was 12 618 000. A raising factor of 3.21 was required to bring the returns per million fish landed to the raised Grimsby level (Table 4). The only other country to return any quantity of tagged spurdogs was France. No data were available from which the rate of non-reporting from this country for this fishery could be calculated, but work done by the author on the Channel stock of spurdogs shows that a raising factor of 5.5 was required to allow for this. The numbers returned from all other sources, which were very small, were taken as actual numbers.

The correction factors are high but the methods of handling spurdogs at sea and on the market are not favourable to a high rate of return. As stated earlier the fish on Grimsby trawlers are not gutted, nor are they on Norwegian liners. On these two types of vessels handling is minimal. During unloading at British ports the fish are handled by their tails, as many fish being held in each hand as possible. The first operation in skinning is to remove the dorsal fins, and if the tag is not noticed at this point the chance of it being seen subsequently is negligible. The fish are handled very quickly, a competent skinner only glancing at the fish as he removes the fins. It would be expected that the maximum rate of return would be from the port

Table 3 Returns of spurdogs tagged during Cruise X/1961 of R.V. CLIONE and Cruise II/1962 of R.V. ERNEST HOLT

Cruise	Fish		Condition category	Number tagged	Number recaptured	Percentage recaptured	Estimated tagging mortality (%)	Effective number tagged
	Sex	Length						
R.V. CLIONE X/1961	♀	80 cm +	Good	85	23	27.1	—	85
			S+L	412	89	21.6	18.2	337
	♀	< 80 cm	Good	614	44	7.2	—	614
	♂	All fish						
	♀	< 80 cm	S+L	1 929	108	5.6	21.9	1 506
	♂	All fish						
R.V. ERNEST HOLT II/1962	♀	80 cm +	Good	226	27	12.0	—	226
			Moderate	338	29	8.6	28.1	243
			Poor	160	12	7.5	37.5	100

S+L = Scratched and Lacerated

Table 4 Calculation of raising factors for non-reporting of tagged spurdog recaptures at Grimsby, and at Fleetwood and in Norway and Scotland, based on landings in 1962

Returns at Grimsby

Source	Tags
Before sales (crew and *lumpers*)	25
After sales (buyers and skinners)	12
Total of actual returns	37
After-sales total × 4 (to allow for non-reporting)	48
Estimated number of tagged fish caught	73
Raising ratio (=73/37)	1.97

Raising factors for other return sources, based on landings in 1962

Port or country	Estimated number of fish landed	Actual number of tags returned	Actual number of tags per million fish landed	Raising factor	Raised number of tags per million fish landed
Grimsby	1 796 000	13	7.24	1.97	14.26
Fleetwood	497 000	6	12.07	1.18	14.26
Norway	12 618 000	56	4.44	3.21	14.26
Scotland	2 230 000	15	6.73	2.12	14.26

where the fish are handled most; this is Fleetwood, where the return rate was in fact the highest. This suggests that the correction factors are of the right order, although that for Norway is unexpectedly high compared with Grimsby, the handling methods being similar.

3 *Loss of tags occurring in the course of the experiment* The Petersen discs were fastened at the base of the first dorsal fin, using either titanium wire or stainless steel wire. Gulland (1963) has shown that the loss of Petersen discs attached to plaice with stainless steel wire is 2.5 per cent a year; there is no significant difference between the rates of return of fish tagged with Petersen discs attached with stainless steel wire and those attached with titanium wire (Williams 1963). Olsen (1953) found that school sharks tagged by this method lost the discs because the fin split, but he inserted his tags high in the dorsal fin, whereas on spurdogs the wire holding the discs was inserted through the muscle at the base of the fin. Neither enlargement of the hole made by the wire nor splitting of the fin was observed or reported, and it is considered that tag losses were negligible.

4 *Additional mortality of tagged fish* The position of the tag was unlikely to have any adverse effect on the fish and it is improbable that the tags caused any additional mortality throughout the experiment.

5 *Emigration* Both Aasen (1962, 1963 and 1964) and Holden (1965) have shown that some tagged fish are caught outside the normal area for this stock, in the Barents Sea, to the west and south of Ireland, in the Irish Sea and in the Bay of Biscay. Holden (1965) considers that there is an Atlantic stock, which mixes with the Scottish–Norwegian stock during part of the year, and that some of the fish tagged in these experiments will be from this stock.

6 *Variations in fishing effort* If fishing effort increases during the period of time over which tagged fish are returned the total mortality rate will be underestimated; it will be overestimated if fishing effort decreases. To correct this possible error the numbers of returns have been divided by the landings of dogfish from Regions IVA and VIA by England, Scotland and Norway for each year, it being assumed (in the absence of effort data) that total catch is proportional to effort. These figures will underestimate the total catch of spurdogs, in that they exclude landings from these two regions by other countries, but will overestimate them in that they will include catches of other species of dogfish. These two errors will tend to cancel each other.

7 *Unequal vulnerability to capture of tagged fish* The Norwegian fishery uses long-lines, to which tagged fish will be no more vulnerable than untagged fish. In the case of trawls or seines it is improbable that the tag, being at the base of the dorsal fin, will result in retention of many fish through the discs being caught on the meshes of the net.

8 *Non-uniform mixing of tagged fish* To obviate this the returns within the first two months following tagging were omitted from the calculations of mortality, and in the case of the two winter taggings (from the R.V. ERNEST HOLT and M.V. OCEAN STAR), when the stock is split, this period was extended to the first four months following tagging.

Estimates of total mortality are liable to error from all six of factors 3 to 8, and also from factor 2 if the rate of non-reporting varies with time. Of these it is considered that errors from 3, 4 and 7 are negligible; the agreement between the results of Margetts (1963) and those given in this paper indicates that the rate of non-reporting has not varied with time; correction has been made for errors arising from factors 6 and 8. The only factor that is liable to be a major source of error is emigration.

THE ESTIMATION OF THE TOTAL MORTALITY COEFFICIENT Z

TAG RETURN DATA

ESTIMATES of the total mortality coefficient were made using the formula:

$$\log_e n_r = -Ztr + \log_e\left[\frac{FN_o(1-e^{-Zt})}{Z}\right] \quad (1)$$

where n_r =number of recaptures, adjusted for fishing effort, in rth period of time t

Z =instantaneous total mortality coefficient

F =instantaneous fishing mortality coefficient

N_o=effective number of fish tagged.

The corrected number of returns was used, because the proportion of tags returned by each country varies throughout the year.

A plot of the Napierian logarithm ($\log_e$) of the number of returns per unit period of time against time gives a straight line relationship whose slope equals $-Zt$. This relationship was calculated for each liberation, splitting the returns into three groups, those of females 80 cm and longer, females less th an 80 cm, and all males, the lengths referring to the length at liberation. The results are shown in Table 5.

Table 5 Estimates of the total mortality coefficient Z calculated, for each liberation of spurdogs, from the number of tags returned per unit time, corrected for fishing effort

	Year of tagging	Ship	Cruise	Z
Females 80 cm and longer	1961	R.V. CLIONE	X	0.806
	1962	R.V. ERNEST HOLT	II	0.867
Females smaller than 80 cm	1961	R.V. CLIONE	X	0.348
Males	1961	R.V. CLIONE	X	0.296
	1961	R.V. CLIONE	XII	0.306
	1962	M.V. OCEAN STAR	—	0.122

The total mortality coefficient was also estimated from the annual decrease in the returns of tags by Grimsby trawlers in relation to their fishing effort, this estimate being unbiassed by death of the fish immediately after tagging or by incomplete reporting of tags, if this remains constant. The effort statistic used was the total hours fishing of all vessels landing spurdogs, calculated by the method described earlier. The results are shown in Table 6.

Table 6 Estimates of the total mortality coefficient Z derived from the annual decrease in the actual numbers of tags returned per 10 000 hours fishing by Grimsby trawlers

	Year of tagging	Ship	Cruise	Year of returns	Number of tags	Tags per 10 000 hours fishing	Z
Females 80 cm and longer	1961	R.V. CLIONE	X	1961	4	1.55	
				1962	2	1.07	0.654
				1963	3	0.90	−0.924
				1964	0	0.00	—
	1962	R.V. ERNEST HOLT	II	1962	2	1.36	
				1963	2	1.80	−0.278
				1964	1	0.42	1.470
			Mean	—	–	—	*0.231*
Females smaller than 80 cm	1961	R.V. CLIONE	X	1961	3	1.55	
				1962	2	1.07	0.371
				1963	1	0.90	0.174
				1964	0	0.00	—
			Mean	—	–	—	*0.273*
Males	1961	R.V. CLIONE	X	1961	5	2.59	
				1962	7	3.74	−0.365
				1963	2	1.80	0.734
				1964	2	0.84	0.755
	1961	R.V. CLIONE	XII	1961	0	0.00	
				1962	3	1.60	—
				1963	1	0.90	0.580
				1964	1	0.42	0.755
	1962	M.V. OCEAN STAR	—	1963	7	6.31	
				1964	7	2.94	0.755
			Mean	—	–	—	*0.536*

The majority of the estimates obtained using this method differ considerably from those obtained from the relation of tags returned with time. Two reasons exist for this:

1 The estimates are based on very few returns, with the result that even small fluctuations in the rate of non-reporting or in the randomness of catching of tagged fish will result in big differences in the estimate of the total mortality coefficient. If, for example, there had been six returns in 1963 and eight returns in 1964 from the liberation from the M.V. OCEAN STAR the estimated total mortality coefficient would have been 0.48 compared with the actual figure of 0.76.

2 The estimates are based on a maximum of four years' returns. Fluctuations in availability have occurred (see later), the effect of which will be most apparent on those estimates derived from the smallest number of comparisons. In consequence the estimates derived from this method of calculation will be less reliable than those calculated by other methods.

AGE COMPOSITION DATA

The number of spurdogs in each age group landed at Grimsby per 100 hours fishing by trawlers fishing regions IVA and VIA for the years 1960 (when market-sampling started) to 1963 are shown in Table 7. Using the methods described by Gulland (1964) the total mortality coefficient was calculated for each year-class between successive years (Table 8). Inspection of the results shows that the total mortality coefficient of the male fish can be considered constant for each year after the age at which full recruitment occurs (seven years); for females, however, the lifespan can be split into three parts: 1 to 4 years, during which recruitment is occurring and the total mortality is low; 5 to 15 years, when the total mortality is approximately the same as that of male fish; and 15 years and older, when the total mortality is high. For both

Table 7 Numbers of spurdogs, by sexes, landed per 100 hours fishing by Grimsby trawlers working regions IVA and VIA, in the years 1960 to 1963

	Age (years) 1	2	3	4	5	6	7	8	9	10	11
Females											
1960	0	59	259	587	591	493	379	338	262	475	250
1961	7	125	181	207	286	331	184	212	243	195	148
1962	13	252	785	554	453	218	285	102	111	97	76
1963	0	14	180	190	451	403	391	466	279	204	178
Males											
1960	1	30	201	472	563	434	737	486	470	236	238
1961	1	80	77	165	336	371	332	405	335	217	291
1962	2	228	501	502	483	467	758	614	530	278	270
1963	0	8	153	373	455	406	582	652	451	326	140

Table 7—continued

	Age (years) 12	13	14	15	16	17	18	19	20	20+
Females										
1960	316	210	230	223	101	104	77	34	35	138
1961	207	196	185	113	100	88	104	74	39	205
1962	64	89	79	57	23	6	19	14	15	92
1963	211	121	116	119	80	61	13	26	32	224
Males										
1960	307	153	168	30	5	5	5	0	21	21
1961	226	309	199	154	66	87	55	30	49	105
1962	137	232	339	115	31	104	87	6	69	135
1963	190	203	213	126	81	148	46	49	24	55

sexes the total mortality coefficient has also been calculated using the catch-curve method, that is, using the data for each year separately. The results are shown in Table 9, in which, to facilitate comparison, the means of the results from Table 8 have also been included. To permit comparison between estimates of mortality coefficients from age composition data and those from tag returns, estimates from fish older than 15 years from the former data have been equated with estimates from fish longer than 80 cm from the latter data, and correspondingly for the younger and smaller fish. The results clearly show the much higher fishing rate on the older female fish, a reflection of the effect of the Norwegian fishery.

Table 8 Estimates of the total mortality coefficient Z for spurdogs of each year-class in successive years, calculated from Table 7

	Total mortality between ages								
	2/1	3/2	4/3	5/4	6/5	7/6	8/7	9/8	10/9
Females									
1961/1960	—	−1.122	0.223	0.713	0.580	0.994	0.580	0.329	0.301
1962/1961	—	−1.837	−1.118	−0.784	0.275	0.151	0.598	0.654	0.916
1963/1962	−0.077	0.343	1.427	0.211	0.117	−0.582	−0.495	−1.008	−0.610
Mean	—	*−0.871*	*0.177*	*0.047*	*0.324*	*0.188*	*0.228*	*−0.009*	*0.202*
Males									
1961/1960	—	−0.943	0.199	0.343	0.416	0.275	0.598	0.371	0.777
1962/1961	—	−1.834	−1.875	−1.075	−1.329	−0.713	−0.615	−0.270	0.186
1963/1962	—	0.401	0.301	0.094	0.174	−0.223	0.151	0.315	0.478
Mean	—	*−0.792*	*−0.458*	*−0.213*	*−0.246*	*−0.221*	*0.045*	*0.139*	*0.480*

Table 8—continued

	Total mortality between ages								
	11/10	12/11	13/12	14/13	15/14	16/15	17/16	18/17	18+/17+
Females									
1961/1960	1.171	0.186	0.478	0.128	0.713	0.799	0.139	0.000	−0.113
1962/1961	0.942	0.844	0.844	0.916	1.171	1.610	2.813	1.514	1.238
1963/1962	−0.610	−1.023	−0.637	−0.262	−0.412	−0.337	−0.975	−0.775	−0.698
Mean	*0.501*	*0.003*	*0.229*	*0.260*	*0.491*	*0.690*	*0.659*	*0.246*	*0.142*
Males									
1961/1960	−0.207	0.051	−0.010	−0.262	0.083	−1.506*	—	—	—
1962/1961	−0.215	0.755	−0.030	−0.095	0.545	0.236*	—	—	—
1963/1962	0.693	0.357	−0.392	0.083	0.994	0.301*	—	—	—
Mean	*0.090*	*0.388*	*−0.144*	*−0.091*	*0.541*	*−0.323**	—	—	—

* Ages 15+/14+

Estimates of the total mortality coefficient derived from indices of abundance of the same year-class in successive years are not subject to bias except for that caused by availability changes. Such changes have occurred over the four years for which information is available. In 1962 there was a very poor summer fishery, especially by the Norwegians (Anon. 1962*a*, 1962*b*), and this is reflected in the negative mortality coefficients for female fish obtained from the 1963/1962 comparison (Table 8). The catch-curve method does not give an unbiassed estimate of the total mortality coefficient for a viviparous species such as the spurdog, when the stock is not stable; the number of young born must depend closely on the size of the mature female stock. As a result, when the stock is declining the total mortality coefficient obtained by the catch-curve method will be underestimated; the youngest fish entering the fishery will be relatively scarce compared with the older fish, because the stock has declined and in consequence recruitment also. If the stock is increasing the opposite will be true. Only at stable stock levels will estimates be unbiassed. Heavy fishing of the Scottish–Norwegian stock did not commence until 1952, when the total catch by the three countries which mainly exploit this stock (Norway, England and Scotland) exceeded 20 000 tons for the first time. Because male fish are not fully recruited to the fishery until 7 years of age the effect of a decline in recruitment will not yet be evident for the males but should already be seen in the female stock. Although estimates of the total mortality coefficient for female fish calculated from comparisons of the same year-class in successive years are higher than those calculated by the catch-curve method (Table 9), there is no evidence that recruitment has declined. For females of 5 years to 15 years the difference between the two estimates is 0.066, but it is greater than this (0.132) for females older than 15 years. The older fish, being recruited before heavy fishing began, should not show the effects of a decline in recruitment, and the fact that they apparently do must be attributed to sampling errors.

Table 9 Estimates of the total mortality coefficient Z for spurdogs, by sexes, calculated using the catch-curve method, and compared with the mean values from Table 8

	Males		Females	
	Ages 7 to 20	Ages 5 to 20	Ages 5 to 15	Ages 15 to 20
1960	0.443	0.172	0.090	0.367
1961	0.187	0.106	0.087	0.278
1962	0.255	0.228	0.185	0.285
1963	0.219	0.212	0.156	0.327
Mean	0.276	0.179	0.129	0.314
	Estimates from Table 8, being the mean values for ages:			
	8/7 to 15+/14+ 0.125	4/3 to 18+/19+ 0.273	4/3 to 14/13 0.195	15/14 to 18+/19+ 0.446

THE INTERPRETATION OF THE RESULTS IN RELATION TO THE STOCKS

THE ATLANTIC STOCK

ALMOST all estimates of the total mortality coefficient derived from the data of tags returned per unit time exceed the estimates derived from age data. The only factor which would bias the results and for which no correction has been made is emigration from the stock. As stated earlier, Holden (1965) has suggested that there is an Atlantic stock which overwinters in the Bay of Biscay and south of Ireland and migrates north during the spring, possibly as far as the Barents Sea, making a return migration in the autumn. During the course of this migration it passes through the Scottish–Norwegian stock on the north of Scotland grounds. The belief in its existence is based on the recapture of fish, tagged off the north of Scotland grounds, in the Barents Sea (Aasen 1964) and to the west and south of Ireland in the Irish Sea and in the Bay of Biscay (Aasen 1964, Holden 1965); further evidence for it is found in the north-south summer-winter movement of spurdogs tagged in the Irish Sea (Holden 1962).

Estimates of the total mortality coefficient calculated from tag returns from liberations on the north of Scotland grounds should be higher than those from liberations on the Norwegian coastal grounds, because the former include a factor caused by emigration. Comparison of the estimated total mortality coefficients shows the reverse to be true (Table 10). In this table only estimates for females longer than 80 cm are shown for the English liberations, because insufficient male fish and smaller females have been tagged off the Norwegian coast to obtain estimates of the total mortality rate.

If the fish of the Atlantic stock do not remain on the north of Scotland grounds, but are found there only briefly during a migration further north, then the chance of catching a tagged fish of this stock there subsequent to the year following release should be negligible, because the proportion of tagged fish on the north of Scotland grounds will be small after mixing of tagged and untagged fish has occurred, and also because the time spent on the grounds, in which they are available for capture, is, in theory, short. If this hypothesis is correct emigration should effectively occur within one year of liberation. Analysis of the tag returns from releases on the north of Scotland grounds, for those periods when both stocks are present, should show (i) a very high estimate of the total mortality coefficient based on the returns during the first years, (ii) a low estimate based on the returns subsequent to the first year following release, and (iii) an intermediate value when all the returns are used. For other releases all three estimates should be the same. Estimates of the total mortality coefficient for the first year were calculated from the difference between the slopes of the two regressions of all returns, and of all returns excluding those from the first year, on

Table 10 Comparison of mean estimates of the total mortality coefficient Z calculated from tags returned per unit time from English and Norwegian liberations of tagged spurdogs off the Norwegian coast and off the north of Scotland; the Norwegian estimates are calculated from data given by Aasen (1964)

Area of tagging	English liberations*	Norwegian liberations
Norwegian coast	0.867	0.836
North of Scotland	0.806	0.689

* Females 80 cm + only

time. For the English results this avoided any bias caused by the small number of observations available in the first year, and it also enabled the Norwegian data (Aasen 1964) to be used.

The method of calculation, using the results from Cruise X/1961 of R.V. CLIONE for female fish smaller than 80 cm, was as follows. The equation for the regression of number of tags returned on time for all years was calculated as

$$w = 3.9947 - 0.1144t \tag{2}$$

where w = $\log_e$ number of tags returned, corrected as described in the text, in a time period t of 120 days.

From this equation

$$Z = \frac{0.1144 \times 365}{120} = 0.348.$$

Excluding the returns in the first year following release gave a regression equation

$$w = 3.8219 - 0.09368t \tag{3}$$

from which

$$Z = 0.285.$$

To obtain an estimate of Z in the first year following release the value of w for $t = 3$ periods of 120 days was calculated from regression 3. The slope of the line joining this point to that of the intercept of regression 2 was then calculated as

$$\frac{(3.9947 - 3.5409)}{3} = 0.1513;$$

from this, Z in the first year $= \frac{0.1513 \times 365}{120} = 0.460.$

The steps are illustrated in Figure 1. The results (Table 11) are consistent with the hypothesis; the estimates of the total mortality coefficient calculated from all the Norwegian coastal releases and from the M.V. OCEAN STAR liberation are lower for the first year than for subsequent years, with one exception, Norwegian liberation 7, for which the estimate was marginally higher (by 0.031) for the first year than for subsequent years. For liberations off the north of Scotland the estimates of the total mortality coefficient for the first year only are higher than those for subsequent years, with two exceptions, that from the M.V. OCEAN STAR and that for male fish released during Cruise X/1961 of R.V. CLIONE. The work from the M.V. OCEAN STAR was done in December, a period when fish of the Atlantic stock would not be expected to be present on the north of Scotland grounds. The majority of the male fish tagged during Cruise X/1961 of M.V. CLIONE were caught east of Scotland, an area which does not lie on the supposed migration path of the Atlantic stock. Both these results are therefore consistent with the hypothesis.

A result that is inconsistent with the hypothesis is that from the Norwegian experiment number 5. This release was made in July and August, compared with November for the other liberations on the north of Scotland grounds. In November mixed catches of the two stocks would be expected, because then the fish of the Atlantic stock would be on their southward migration, but in July and August these fish should be north of the Scottish grounds. To determine whether the spurdogs on the north of Scotland grounds during the summer months are a mixture of the Scottish–Norwegian and Atlantic stocks the numbers of fish in each age group landed at Grimsby were compared for the two six-month periods, November to April and May to October. During the former period only the Scottish–Norwegian stock should be present, but during the latter period both stocks, if mixing has occurred. Because the Atlantic stock inhabits for part of the year areas west and south of Ireland and the Bay of Biscay, where fishing intensity is probably lower than on the north of Scotland grounds (there are no comparable effort data), the fishing mortality on it should be lower than that on the Scottish–Norwegian stock. Therefore estimates of the total mortality coefficient calculated from the May to October data should be lower than those from the November to April data. For male fish this was true, but examination of the data (Table 12) indicated that the high

estimates of the total mortality coefficient for the winter period may have been due to an absence of the older fish. Comparison of the mean total mortality coefficients for fish of 8 years to 15 years old for the two six-month periods shows only a small difference between them. (It is possible that the older the fish the greater likelihood that they will move to the Norwegian coast during the winter). For female fish the mean of the estimates of the total mortality coefficient for the summer period is higher than that for the winter period. There is thus no evidence to indicate that the spurdogs on the north of Scotland grounds during the summer months contain a large proportion of fish of the Atlantic stock. The mortality estimates from the Norwegian release No. 5 are based on returns from three years only, and the discrepancy is therefore most probably due to chance caused by insufficient observations.

The remaining data are consistent with the hypothesis but they do not explain why mortality estimates derived from liberations off the Norwegian coast are higher than those calculated from releases on the north of Scotland grounds, unless the hypothesis is extended to include a separate Norwegian coastal stock, for whose existence there is some evidence.

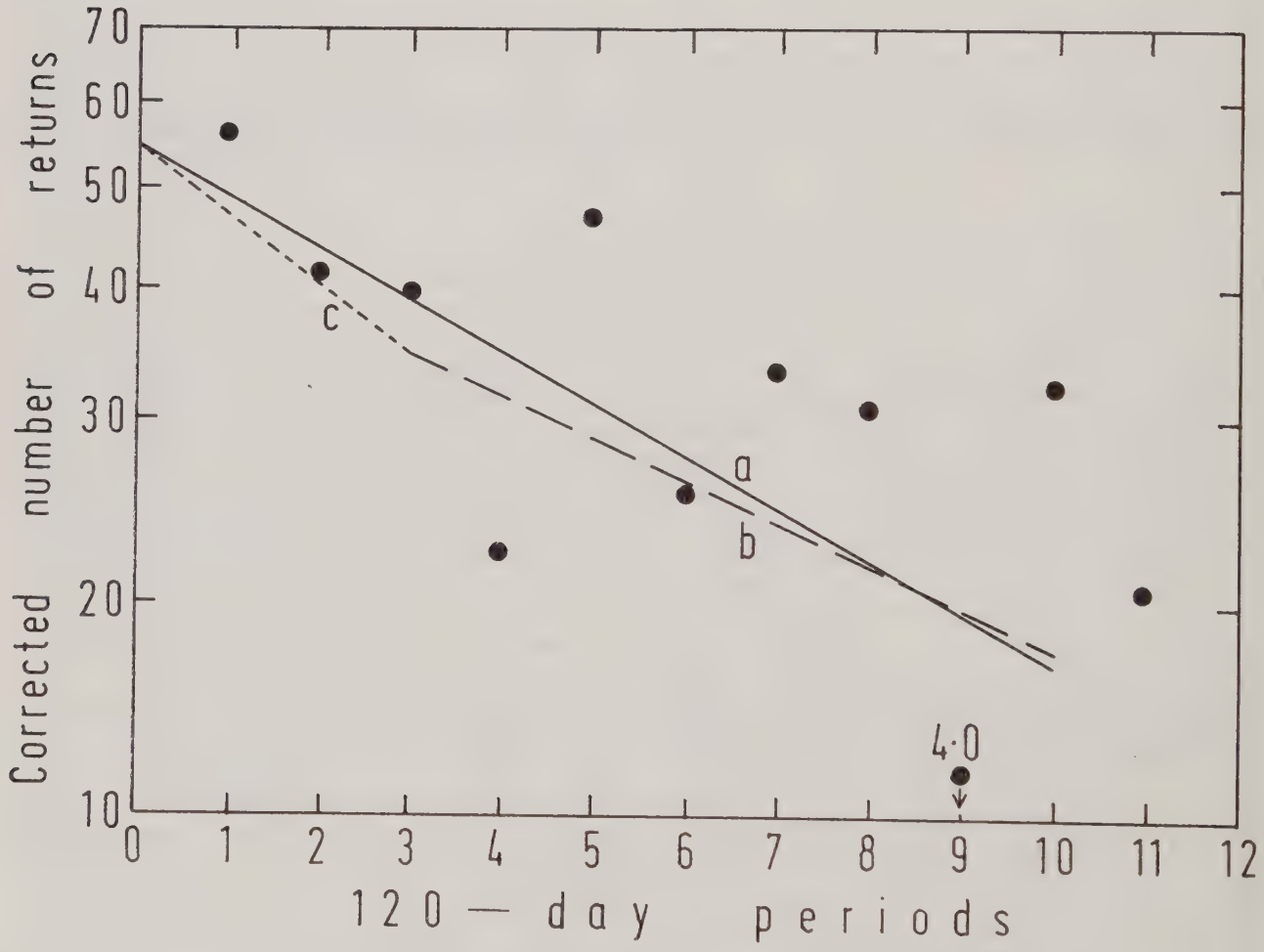


Figure 1 Method of calculation of the total mortality coefficient Z for the first year following liberation, using data for female spurdogs smaller than 80 cm, Cruise X/1961 of R.V. CLIONE: a = regression calculated using all returns; b = regression calculated using all returns except those during first year; c = derived regression, from which the first-year Z is obtained.

Table 11 Comparison of estimates of the total mortality coefficient Z calculated using all returns of tagged spurdogs, returns subsequent to the first year after liberation, and returns for the first year only (from the difference between the first two of these); for English results the returns from the first two or four months, depending on the position of release, have been omitted to allow for the mixing of tagged and untagged fish

Area	Liberation	Sex	Estimated Z		
			1st year only	All returns	2nd year +
Norwegian coast	Norway 3	No data	0.804	1.110	1.246
	Norway 7	No data	0.898	0.879	0.867
	R.V. ERNEST HOLT	♀, 80 cm +	0.849	0.867	0.868
North of Scotland	Norway 1		0.981	0.630	0.530
	Norway 2		0.701	0.546	0.481
	Norway 5		1.360	0.982	0.342
	R.V. CLIONE X/61	♀, 80 cm +	0.900	0.806	0.687
		♀ <80 cm	0.460	0.348	0.285
		♂	0.273	0.296	0.307
	R.V. CLIONE XII/61	♂	0.707	0.306	0.057
	M.V. OCEAN STAR	♂	0.012	0.122	0.218

Table 12 Estimates of the total mortality coefficient Z for male and female spurdogs, calculated using the catch-curve method, split by six-month periods: for the period December to April the year refers to that in which the period ends

		1961	1962	1963	Mean
Males, 8–20 years	May–November	0.201	0.371	0.426	0.333
	December–April	0.310	0.544	0.552	0.469
Males, 8–15 years	May–November	0.510	0.029	0.143	0.228
	December–April	0.617	0.049	0.225	0.297
Females, 5–20 years	May–November	0.084	0.167	0.218	0.156
	December–April	0.096	0.104	0.205	0.135
Females, 5–15 years	May–November	0.015	0.132	0.073	0.074
	December–April	0.162	−0.101	0.237	0.069
Females, 15–20 years	May–November	0.102	0.143	0.553	0.266
	December–April	−0.040	0.310	0.127	0.132

EVIDENCE FOR A NORWEGIAN COASTAL STOCK

From reports in *Fiskets Gang* it is known that a summer fishery for spurdogs occurs off the Norwegian coast and there have been returns of both Norwegian- and English-tagged fish from this coast during the summer. Comparison of the Norwegian returns for the quarter July to September in the years 1959 to 1961 and 1963 (Aasen 1962, 1964) shows that the number of recaptures off the Norwegian coast has increased, but in the absence of any data on fishing effort it is not possible to state whether this is due to there being more tagged fish on these grounds or to increased fishing effort. The returns were therefore examined to see whether a fish was more likely to be recaptured in the area in which it was tagged. Using the Norwegian data and English returns of females of 80 cm and longer (the Norwegian fishery is mainly for fish of this size and sex; inclusion of small female fish and males would therefore bias the calculations), the recaptures of tagged fish for the period April to September were grouped into four categories—releases on the north of Scotland grounds and those off the Norwegian coast, divided into recaptures east and west of 1°E (Table 13). Although it would be better to examine the returns over a shorter period, May to August, when all the stock might be expected to be on the north of Scotland grounds, the Norwegian data are only given by quarters and there are too few English returns to examine separately. Applying a chi-squared test to these data gives a result of 15.6, which is significant at less than the 0.001 level of probability. Therefore fish tagged off the Norwegian coast are more likely to be recaptured in that area during the period April to September, and this suggests that there may be a coastal Norwegian stock which does not migrate, except possibly along the Norwegian coast. The existence of two stocks would explain the discrepancy between the total mortality coefficients derived from the releases in the two areas.

Table 13 Comparison of the number of all Norwegian returns and of English returns of female spurdogs of 80 cm and longer, for the period April to September, from east and west of 1°E from liberations on the north of Scotland grounds and off the Norwegian coast; the first year's returns are omitted

Area of tagging	Area of recapture	
	W of 1° E	E of 1° E
Norwegian coast	28	35
North of Scotland	144	57

$\chi^2 = 15.6$, $P < 0.001$

THE ESTIMATION OF THE FISHING MORTALITY COEFFICIENT *F*

THE fishing mortality coefficient was estimated using equation 1, the intercept of which is

$$\log_e\left[\frac{F.\,N_0(1-e^{-Zt})}{Z}\right] \tag{4}$$

Allowance was made for tagging mortality, determined from the condition at release as described earlier, to obtain the effective number of fish tagged N_0. This value was used to estimate the fishing mortality coefficient for the Norwegian coastal liberation (from R.V. ERNEST HOLT) and for those liberations on the north of Scotland grounds from which the estimates of the total mortality coefficient show that emigration did not occur (male fish from R.V. CLIONE and from the M.V. OCEAN STAR). For the other releases, for which these estimates showed that emigration had occurred, the estimate of the total mortality coefficient for the first year was used to calculate the number of survivors from the Scottish-Norwegian stock, this value being taken as N_0. The intercept was calculated from the regression of tags returned subsequent to the first year on time. The results are shown in Table 14.

Table 14 Estimates of the fishing mortality coefficient *F* for spurdogs, calculated as described in the text

Liberation	Sex	*F*
R.V. ERNEST HOLT II/1962	Females 80 cm +	0.537
R.V. CLIONE X/1961	Females 80 cm +	0.609
	Females <80 cm	0.125
	Males	0.133
R.V. CLIONE XII/1961	Males	0.142
M.V. OCEAN STAR	Males	0.104

THE ESTIMATION OF THE NATURAL MORTALITY COEFFICIENT *M*

ESTIMATES of the natural mortality coefficient were made by subtracting the estimates of the fishing mortality coefficients from those of the total mortality coefficients, obtained from tagging data (Table 15). The Norwegian data have been included in the results, making the assumption that these data refer mainly to female fish longer than 80 cm. There is considerable variation in the results and, in order to determine their validity, the constant mortality rate at which the female stock would replace itself was calculated using the regression of fecundity on length given by Holden and Meadows (1964). This gives a mean value of 0.175, with a range of 0.145 to 0.205, obtained from the 95 per cent confidence limits of the regression, compared with a mean of 0.103 from the results in Table 15. This constant mortality rate at which stock replacement occurs must be a close approximation to the natural mortality rate, if it is assumed that the stock was in equilibrium before fishing started and that there has been neither a compensatory increase in fecundity nor a decrease in the natural mortality rate, as a result of fishing. If the mean value is a true estimate it would mean that the unexploited stock would have an excess reproductive potential, assuming that no compensation for fishing has occurred. Holden and Meadows (1964) considered this possibility and postulated a mechanism by which the population could remain in equilibrium, the mechanism being predation of the newly born young by the spawning females at high stock density, the predation decreasing as stock abundance decreased. Thus at high abundance levels the surplus reproductive potential would be removed. The mean value is also in agreement with the theory of Beverton and Holt (1959), linking the natural mortality coefficient with the von Bertalanffy growth constant *K*. It has therefore been used as a working estimate of the natural mortality coefficient.

Table 15 Estimates of the natural mortality coefficient *M* for spurdogs, from tag data

Sex	*Z*	Data for *Z*	*F*	*M*
Females 80 cm +	0.687	R.V. CLIONE X/1961	0.609	0.078
	1.110	Norway 3		0.537
	0.879	Norway 7		0.306
	0.530	Norway 1	0.573*	−0.043
	0.481	Norway 2		−0.092
	0.342	Norway 5		−0.231
	0.867	R.V. ERNEST HOLT II/1962	0.537	0.330
Females 80 cm	0.285	R.V. CLIONE X/1961	0.125	0.160
Males	0.296	R.V. CLIONE X/1961	0.133	0.163
	0.057	R.V. CLIONE XII/1961	0.142	−0.085
	0.122	M.V. OCEAN STAR	0.104	0.018
Mean				0.103

* Mean of values for R.V. CLIONE X/1961 (females, 80 cm +) and R.V. ERNEST HOLT II/1962

THE RATIONAL EXPLOITATION OF THE STOCK

As stated in the introduction, the exploitation of the male and female parts of the stock pose different problems. The former can be exploited without considering effects on recruitment; this assumes that the reproductive capacity of the stock is independent of the density of mature males, which is probably true except at very low stock abundance. In exploiting the female stock, however, effects on recruitment must be considered.

THE MALE STOCK

At the present rate of fishing effort a mean length of entry into the fishery of 56 cm would result in the maximum yield per recruit, as calculated from the parameters given in Table 16 and tables of yield functions (Beverton and Holt 1964). Other values of the mean length of entry into the fishery necessary to obtain the maximum yield per male recruit, for different values of the natural mortality rate, assuming a constant total mortality rate of 0.22 ,are given in Table 16.

Table 16 Estimation of the minimum length of entry into the fishery ($l_c = c \times L_\infty$) necessary to give the maximum sustainable yield from the male part of the spurdog stock, using tabulations of the yield curve (Beverton and Holt 1964). The figures in bold type are the most probable values

$L_\infty = 79.7$ cm, $K = 0.21$, $F + M = 0.22$

M	F	E	M/K	c	$c \times L_\infty$ (cm)
0.05	0.17	0.773	0.238	0.85	68
0.10	**0.12**	**0.545**	**0.476**	**0.70**	**56**
0.15	0.07	0.318	0.714	0.52	41

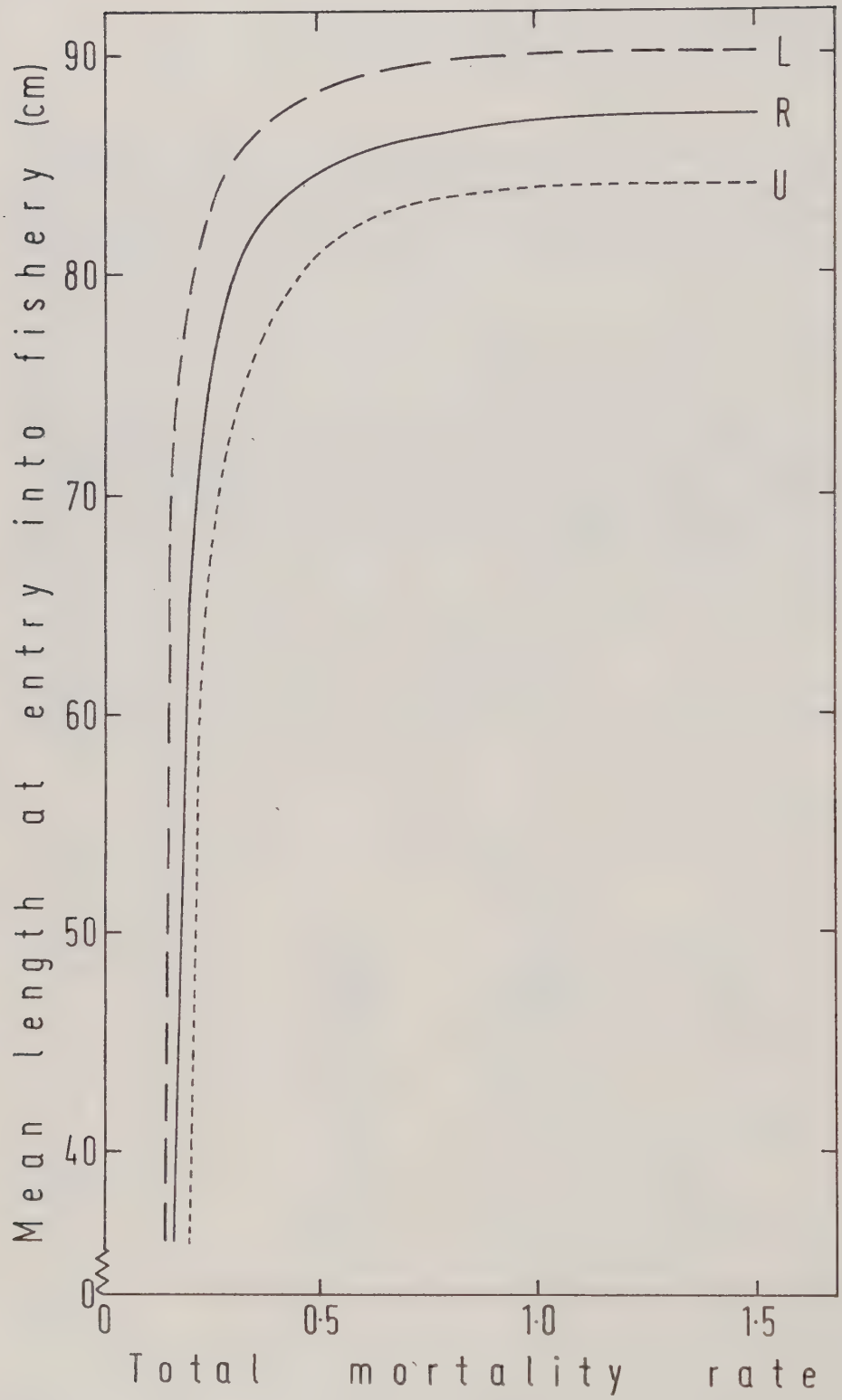


Figure 2
Relationship between the mean length of entry of spurdogs into the fishery and the maximum total mortality coefficient at which recruitment would be maintained constant; the calculations are based on a lifespan of twenty-five years, with a natural mortality coefficient of 0.103, and on the regression of fecundity on length (curve R) and its upper and lower 95 per cent confidence limits (curves U and L), given by Holden and Meadows (1964).

THE FEMALE STOCK

Recruitment of both sexes must be closely related to the stock of mature females, which cannot be exploited with the sole object of obtaining the maximum yield per recruit. If the fishery is not to decline recruitment must be maintained, and the exploitation rate must be adjusted to obtain the maximum yield per recruit that is consistent with the maintenance of recruitment. To distinguish this yield from the more usual maximum yield per recruit it is proposed to term it the best yield per recruit. At the present total mortality rates of 0.173 for females less than 80 cm long (that is, up to 10 years old) and 0.421 for those longer than this (Table 17), recruitment is not being maintained. At these rates an initial cohort of 1 000 female fish will produce between 618 and 246 female young during its lifespan of 25 years—a decline in recruitment of 38 per cent to 75 per cent. These values are based on the fecundity data of Holden and Meadows (1964), using the upper and lower 95 per cent confidence limits of their regression of fecundity on length. The rate of decrease based on the regression formula itself is 61 per cent. For each equation the figures represent the maximum number of possible recruits. If any predation at birth occurs, as suggested above, the number of recruits will be fewer still. To stabilize recruitment either fishing effort must be reduced or the mean length of entry into the fishery (l_c) must be raised, or both. If the present level of fishing is maintained the minimum effective length to which the mean length of entry must be raised to stabilize recruitment is 80 cm; this is based on the upper 95 per cent confidence limit of the regression of fecundity on length (Holden and Meadows 1964).

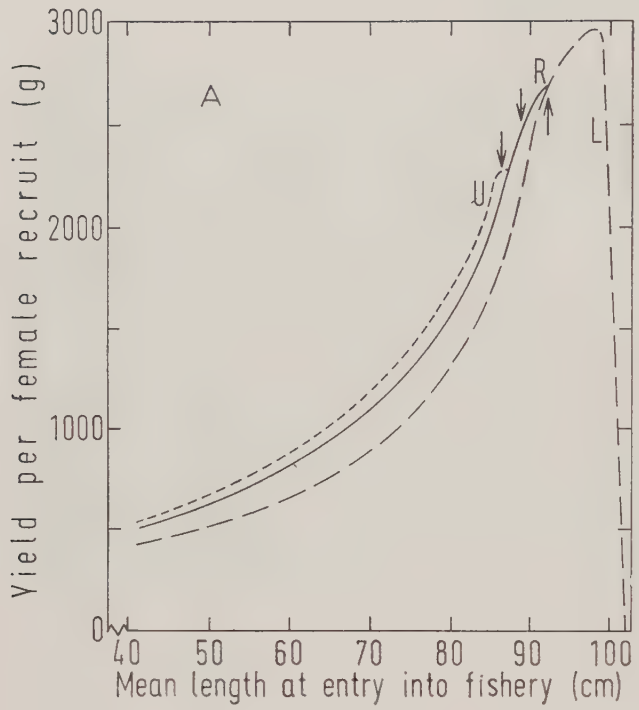
Table 17 Weighted mean total mortality coefficients Z of spurdogs, using data from Tables 8, 9 and 11

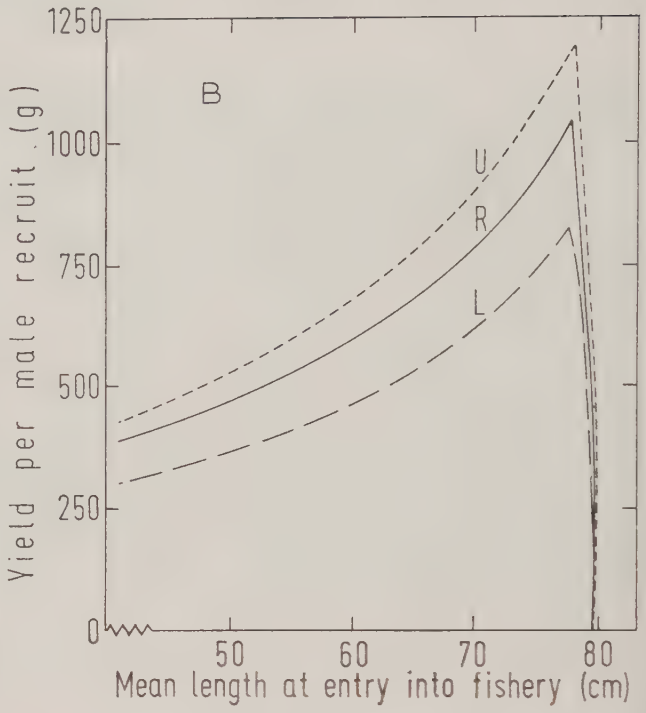
Area	Sex	Z	Data used from Table 11
North of Scotland	Females, 80 cm +	0.421	2nd year +
	Females <80 cm	0.173	2nd year +
	Males	0.195	All returns except R.V. CLIONE XII/61, 2nd year +
Norwegian coast	Females, 80 cm +	0.952	Table 11 data only

EXPLOITATION OF BOTH SEXES

The effective method of altering the mean length of entry into the fishery would be the imposition of a minimum size limit of that length, assuming knife-edge selection. To impose separate size limits for each sex would pose enforcement problems (although the sexes are easily distinguished externally by the presence of claspers in the males only), and therefore the requirements necessary to obtain the best yield per recruit with a single minimum size limit have been considered.

Maintenance of recruitment is determined by four parameters for the female stock—fecundity, mean length of entry into the fishery, and the rates of natural and fishing mortality. The relationship between the total mortality rate at which recruitment would be maintained constant and the mean length of entry into the fishery is shown in Figure 2; the curves are based on a natural mortality coefficient of 0.103 and the regression of fecundity on length and its upper and lower 95 per cent confidence limits given by Holden





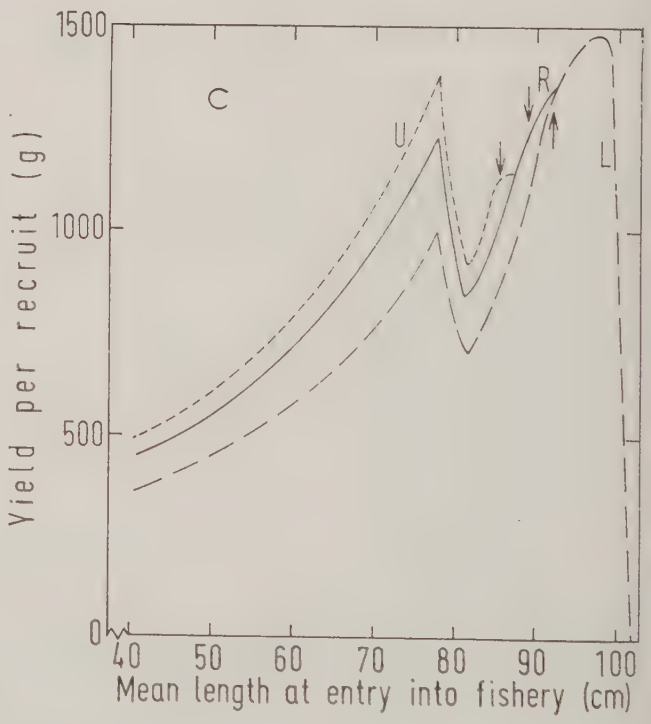


Figure 3a Maximum possible yield per female spurdog recruit, recruitment maintained constant, related to mean length of entry into the fishery.

Figure 3b Maximum possible yield per male spurdog recruit, using the levels of E and l_c defined by the requirements of the female stock.

Figure 3c Maximum possible yield per spurdog recruit, both sexes combined.

The three curves in Figures 3a, b and c are calculated on the same basis as in Figure 2.

and Meadows (1964). A total lifespan of 25 years has been used, because the fecundity data did not include fish older than this. For each pair of values of mean length and total mortality coefficient the rate of exploitation E was calculated, and hence the yield function Y' (Beverton and Holt 1964). These values were converted into yield per recruit by multiplying by:

$$\frac{W_\infty}{(1 - l_r/L_\infty)^{M/K}}$$

where W_∞ =weight at the asymptotic length L_∞

l_r =length at which fish first encounter the fishing gear,

and the other parameters are as described earlier. The parameter l_r cannot be determined precisely, but since the majority of fish in this fishery are line-caught it has been assumed, for the purposes of these computations, that if a minimum size limit were imposed undersized fish would be discarded alive and consequently l_r would approximate to l_c. For each value of l_c the yield per female recruit was calculated (Figure 3a). Similar calculations were made to determine the yield per male recruit that would be obtained at the levels of E and l_c defined by the requirements of the female stock (Figure 3b). These two yield curves are combined in Figure 3c. The yield per recruit rises to a peak at a mean length of entry into the fishery of 78 cm, and then declines as the mean size rises above the asymptotic length of male fish and exploitation of the male stock ceases. It then rises again as the yield per female recruit rises with the increased mean length of entry into the fishery. In Figure 4, these three curves are expressed in terms of the exploitation rate. Above a certain mean length of entry into the fishery, dependent upon the relation between fecundity and length, fishing effort requires to be infinitely great to maintain recruitment constant. This corresponds to a rate of exploitation of unity, which is a practical impossibility. In Figures 3a and 3c a rate of exploitation of unity has been used in calculating the yield per recruit for all lengths above that at which this rate was reached (indicated in each case by an arrow); thus in these figures the three curves eventually join. In Figure 4 the yield per recruit is shown to the initial length at which an exploitation rate of unity would be required, and not for greater lengths. The theoretical best yield per recruit is not a practical possibility.

If the true relation between fecundity and length lies near to its upper 95 per cent confidence limit, the yield per recruit cannot be increased by raising the mean length of entry into the fishery above 78 cm (Figure 3c). If this relation lies near to the regression formula or its lower 95 per cent confidence limit then a higher yield per recruit could be obtained at a greater length, but only by increasing the rate of exploitation to very high levels, which would probably be uneconomic. For example, the best yield per recruit at a mean length of entry into the fishery of 78 cm would be 1 100 g at an exploitation rate of 0.512 (Figure 4, lower 95 per cent confidence limits). This yield could be increased to 1 320 g, but only by increasing the exploitation rate to 0.99, implying a rise in the fishing mortality rate from 0.108 to 10.20.

The best compromise minimum size limit would therefore be 78 cm. This would have to be accompanied by a reduction of the total mortality rate in the female stock to between 0.107 and 0.297 (Figure 2), to maintain recruitment constant. This approximates to the present total mortality rate for the male stock.

It is emphasized that in reading these figures all the curves relate to conditions at which recruitment would be maintained constant, and that in plotting the relation between any two sets of parameters the necessary alterations to all other parameters have been made in the calculations to satisfy this requirement.

It would be possible to adjust the fishing effort on the male stock to obtain a greater yield per recruit. At a mean length of entry into the fishery of 78 cm unlimited exploitation could be permitted, but the parameters given above define the exploitation of the female stock in order to obtain the best yield per recruit, on which it is not possible to improve without affecting recruitment. It is not possible to obtain the maximum yield per female recruit, at any combination of mean length of entry into the fishery and fishing effort, without adversely affecting recruitment.

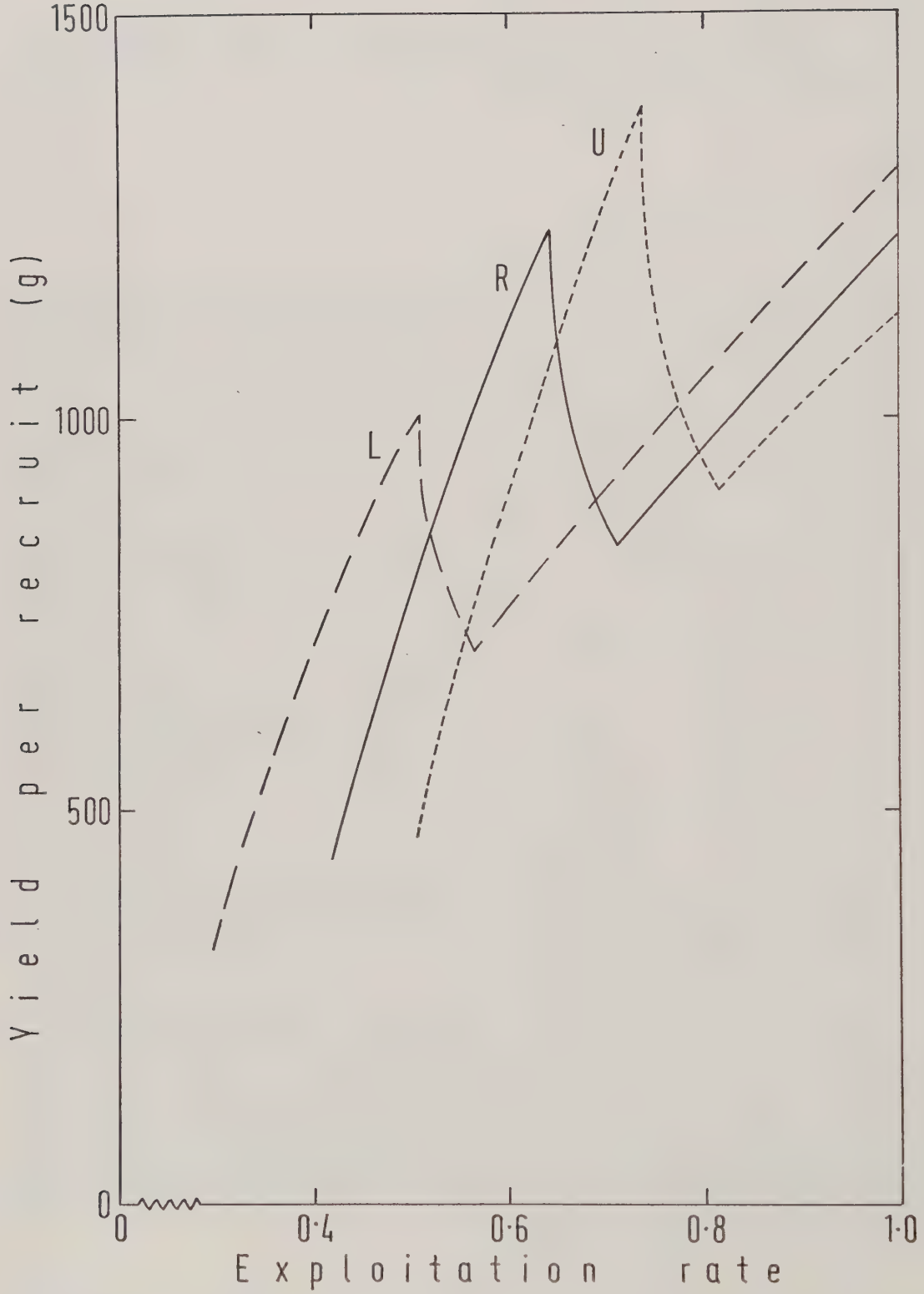


Figure 4 Yield per spurdog recruit, both sexes combined, plotted against the rate of exploitation; the three curves are calculated on the same basis as in Figure 2.

DISCUSSION

It is evident from the above data that if no measures are taken to conserve the Scottish–Norwegian stock of spurdogs the stock will continue to decrease, even if the lowest estimate of the total mortality coefficient is correct. At present the male recruits to the fishery are being fished at a level which will give the maximum yield per recruit, because few fish of less than 56 cm are landed at Grimsby or at Fleetwood; the English fishery is the main exploiter of the male stock. However, recruitment of males will decline because the female part of the stock cannot, at the present rate of fishing, produce enough young to maintain recruitment.

To interpret the results of the tagging experiments it has been necessary to postulate the existence of two other stocks, an Atlantic and a Norwegian stock, for which there is sufficient, if not conclusive, evidence. The effects of including data from the Atlantic stock with those from the Scottish–Norwegian stock will be to some extent self-cancelling. Estimates of the total mortality coefficient obtained from age composition data are likely to be too low, because the Atlantic stock is probably little exploited, while estimates from tag returns will be too high. The effect of including data from the Norwegian coastal stock will be to overestimate the effect of the present fishing effort on the Scottish–Norwegian stock, and in consequence the need for conservation measures to stabilize the yield.

Although the total Norwegian catches have increased fairly steadily since 1957, the greatest rate of increase has been from Norwegian coastal waters, not from the Shetland area (Table 18). There is also evidence, from reports in *Fiskets Gang*, that a summer coastal fishery for spurdogs now exists, which has built up over the past few years. These data are consistent with the total mortality estimates calculated from tag returns, which suggests that the Norwegian coastal stock is smaller than the Scottish–Norwegian stock, with the result that the taking of a moderate catch (the catch taken off the Norwegian coast will be from both stocks) results in a high mortality rate. Comparison of the returns from the earliest Norwegian tagging experiments with those from more recent ones (Aasen 1961, 1964), together with the recent establishment of the summer coastal fishery, indicates that the Norwegian coastal stock may have only recently established itself. It is obvious from the recaptures of fish, tagged on the Scottish grounds, off the Norwegian coast during the summer months (Table 13) that there is not a seasonally clear-cut migratory movement of the Scottish–Norwegian stock and that interchange between the two is still occurring.

Table 18 Norwegian catches of spurdogs, in tons, from 1957 to 1962, divided by regions; taken from Fiskeristatistikk (formerly Norges Fiskerier)

Year	Shetland	Norwegian coastal
1957	9 800	8 904
1958	11 102	11 310
1959	12 048	7 074
1960	13 563	12 092
1961	17 825	13 654
1962	11 755	16 927
1963	8 543	22 670
1964	8 889	15 869

There is an indication that the shift in Norwegian effort has resulted in a decrease in the total mortality rate acting on the stock. Estimates of the total mortality coefficient calculated from returns from the second and later years (Table 11) show a decrease from Norwegian liberations 1 and 2, which cover 1961 to 1963, to liberation 3, which covers 1962 and 1963. The returns from Cruise X/1961 of R.V. CLIONE cover the years 1962 to 1964. The data are very limited but results from later liberations should show to what extent the total mortality coefficient has decreased in relation to the fall in Norwegian catches off the Shetlands in 1963 and 1964 (Table 18).

The conclusions reached in this paper do not agree with those of Aasen (1964) who used the model of Schaefer (1957) to establish the maximum sustainable yield from what he termed the North-east Atlantic stock, which includes all spurdogs caught off the European seaboard. He concluded that although fishing was intense the greatest sustainable yield would be obtained at the present level of effort. These conclusions differ from those reached in this paper, which are that severe restriction of fishing is necessary to prevent a drastic and continuing decline in the stock. However, the Schaefer model as used by Aasen relates the changes (recruitment plus growth minus mortality) in the population, to the present population, whereas the recruitment actually comes from the population of several years previously, and as the population is declining this will have been a larger population. Thus the model will overestimate the sustainable yield from the stock. This fact, and the fact that Aasen treats the North-east Atlantic spurdogs as a single stock rather than as several stocks, of which some, e.g. the Norwegian coast stock, are heavily fished, and others comparatively lightly fished, probably explain the discrepancies between Aasen's conclusions and those reached here.

SUMMARY

1 Estimates of the total mortality coefficients for the Scottish–Norwegian stock of spurdogs were made from age composition data and from tag returns from liberations off the north of Scotland and the Norwegian coast.

2 To explain differences between the values of estimates from the three sources, the existence of an Atlantic stock and a Norwegian coastal stock of spurdogs is postulated. Using this hypothesis further analyses of the data were made, the results being consistent with it.

3 Estimates were made of the fishing and natural mortality coefficients for the Scottish–Norwegian stock.

4 Using the mortality estimates and fecundity data the present rate of decrease of the stock was calculated.

5 To stabilize the stock it was calculated that a minimum size limit of 80 cm for female fish is required, and that a minimum size limit of 56 cm for male fish would result in the maximum yield from this part of the stock at the present rate of fishing.

6 It was calculated that the best yield per recruit obtainable from the entire stock without adversely affecting recruitment would be obtained by introducing a minimum size limit for both sexes of 78 cm, at the same time reducing the fishing mortality rate on the female stock to between 0.107 and 0.297. This lower rate approximates to that for the male stock at present.

7 Because the Scottish–Norwegian stock mixes with the other two stocks at certain times of the year the effect of using data from the mixed stocks is discussed. The effect of including data from the Atlantic stock is considered negligible, but that of including data from the Norwegian coastal stock would lead to an overestimate of the effects of fishing on the Scottish–Norwegian stock.

8 The results obtained are discussed in relation to those obtained by Norwegian workers, with which they disagree. The causes of the disagreement are considered and the reasons for the validity of the present conclusions are stated.

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